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No. 429

HEAT DISSIPATION FROM A FINNED CYLINDER AT
DIFFERENT FIN-PLANE/AIR-STREAM ANGLES

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SUMMARY

This report gives the results of an experimental determination of the temperature distribution in and the heat dissipation from a cylindrical finned surface for various fin-plane/air-stream angles. A steel cylinder 4.5 inches in diameter having slightly tapered fins of 0.30-inch pitch and 0.6-inch width was equipped with an electrical heating unit furnishing 13 to 248 B.t.u. per hour per square inch of inside wall area. Air at speeds from 30 to 150 miles per hour was directed at seven different angles from 0° to 90° with respect to the fin planes.

The tests show the best angle for cooling at all air speeds to be about 45° . With the same temperature for the two conditions and with an air speed of 76 miles per hour, the heat input to the cylinder can be increased 50 per cent at 45° fin-plane/air-stream angle over that at 0° .

INTRODUCTION

The large improvement that has been made during the last few years in the cooling of air-cooled engines has been accomplished by changing the shape and arrangement of the cooling fins, by increasing the thickness of the combustion-chamber walls, by using a metal of high thermal conductivity, and by selecting the best location for the valves, spark plugs, and exhaust ports. (References 1 and 2.) As far as known no work has been done to determine the effect on the cylinder temperatures of directing the cooling air at different angles with respect to the fins.

Cowlings affect the direction of flow of the cooling air and the cylinder temperatures. The tests reported in

reference 3 showed that the use of a cowling that enclosed 35 per cent of the cooling area of the cylinder barrel resulted in satisfactory cooling, the cylinder-head temperatures being lower than those of an engine with no cowling, indicating either that the cowling directed more air past the cylinder heads or that the direction of the air flow was changed in such a manner as to give increased cooling. When a ring cowling is used over an inner cowling the direction of the air flow is more nearly parallel with the fins than when no ring cowling is used. The cylinder-head temperatures have been found to be slightly higher with a ring cowling than with no ring cowling. (Reference 4.)

The quantitative effect of directing the air at different angles can not be obtained from the cowling test data because there are other variables, such as the air velocity between the cylinders and the power output, that influence the results. It would also be difficult to determine the exact angle of the air stream with respect to the plane of the fins.

The object of the present investigation was to determine the temperature distribution in and the heat dissipation from a cylindrical finned surface for various fin-plane/air-stream angles. The finned specimen was tested in a wind tunnel over a large range of air speeds and heat inputs.

APPARATUS

In order that the results might be of greatest practical value the finned specimen was designed to simulate closely the air-flow and heat-flow conditions obtained in an engine. A cylindrical specimen with circumferential finning was selected.

A heating unit of resistance wire embedded in refractory cement was placed in the cylinder to supply the heat. The heat input could be easily regulated and measured and the capacity was sufficient to give the temperatures desired. In the construction of the unit great care was exercised to obtain uniform heating and electrical insulation that would not disintegrate at high temperatures and to have the cement in close contact with the element wire at all points.

The finned specimen used in these tests was cut from the barrel of a Wright J-5 engine cylinder and had a diameter of 4.5 inches. The fins of 0.3-inch pitch were machined to a width of 0.6 inch, the width of the smallest fin on the original J-5 cylinder. The enamel was removed from the cylinder and the tests were conducted with the surface in a semipolished state.

The construction of the heating unit as assembled in the test specimen is shown in Figure 1. The core was made from a 3.5-inch-diameter tube inside of which were welded two webs. In the center of the webs was located a 0.75-inch-diameter tube for supporting the specimen. Small holes were drilled in the surface of the large tube to provide a bond for the cement and to allow the moisture in the cement to escape. Parallel annular grooves of 0.25-inch diameter were cut in the cement for locating the heating coils. The coils were constructed by winding nichrome wire of 0.05-inch diameter in coils of 0.13-inch pitch and 0.25-inch diameter. A method of crossing the coils from one groove to the next was adopted whereby the amount of wire per unit area of cylinder surface was quite uniform. After the coil had been wound on the cemented core another layer of cement was added, making certain that no voids existed between the wires. A jig was then used to center accurately the heating unit in the cylinder, and the space between the cemented element and the cylinder wall was filled with cement. The cement was forced into this space with a hydraulic press so as to eliminate air pockets. The elimination of all air pockets around the coil is very important because if there is not good thermal contact between the wire and the cement the temperature of the wire will be excessive and its current-carrying capacity will be reduced.

Guard rings were placed on each end of the test specimen to decrease the heat flow through the ends and also to obtain 2-dimensional air flow over the specimen. The guard rings are shown assembled in place on the test specimen in Figure 1. These guard rings were in all respects like the test specimen except that they were shorter and had one heating coil each instead of two coils connected in parallel. A 1/32-inch thick asbestos gasket was placed between the guard rings and the test specimen.

In the first part of the test, large copper conductors insulated with mica were used to supply current to the

resistance wire. This construction was not satisfactory because the temperature within the heating unit was high enough to soften the copper and to disintegrate the mica. These difficulties were obviated by the use of conductors of monel and nichrome metal insulated with porcelain. After continued use the monel metal scaled between contacting surfaces causing a large increase in circuit resistance. This difficulty was eliminated by welding all monel metal connections.

The heat input to the main specimen, like that to the guard rings, could be conveniently regulated by means of rheostats. The rheostats were made of nichrome wire mounted on a frame submerged in oil. Three of these rheostats were used so that the heat input to each guard ring and to the specimen could be separately controlled. A wiring diagram for the heating unit, rheostats, and instruments is shown in Figure 2.

A 30-inch closed-throat wind tunnel was constructed to supply the cooling air. The exterior of the entrance cone and test chamber of the wind tunnel and the rheostats are shown in Figure 3. A sketch of this tunnel with the principal dimensions is shown in Figure 4. The air enters the entrance cone through a small-tube honeycomb. Care was exercised in the design of this tunnel so as to produce an air stream as nearly nonturbulent as was reasonably possible. Accordingly, the ratio of entrance cone area to throat area is large and the entrance cone is short compared to the exit cone which has a more gradual increase in area. The resulting flow conditions are considered satisfactory. A 5-foot 4-blade propeller is used for circulating the air. The propeller is driven through a V-belt drive by an electric dynamometer. An air speed of 200 miles per hour has been obtained in this wind tunnel at a propeller speed of 2,200 r.p.m. with a power input of 60 hp.

The method of mounting the test specimen and guard rings in the tunnel is shown in Figure 4. The test specimen and guard rings are bolted together on a mounting tube which is bolted to a semicircular ring. The fin-plane/air-stream angle was varied by changing the position of the mounting tube on this semicircular ring. To one of the guard rings was fixed a bullet-nosed fairing which provided smooth flow when the axis of the specimen was nearly parallel with the air stream.

Two duplex recording pyrometers in conjunction with 24 iron-constantan thermocouples were used for measuring the temperatures at different points on the test specimen. A complete set of readings was obtained every 1-1/2 minutes. The instruments were automatically compensated for cold-junction temperature change. The thermocouple junctions were constructed by the spot welding of 0.013-inch thermocouple wires to the cylinder surface. The thermocouple wires were led directly away from the cylinder surface to a terminal board mounted in the rear of the cylinder in such a manner as to offer the least obstruction to the air stream. Elastic bands were fastened near the ends of these wires to keep them taut and free from wind disturbances.

A differential thermocouple was used between each guard ring and the test specimen to indicate the temperature difference between the adjacent surfaces. These thermocouples were connected to sensitive galvanometers.

A triple-scale ammeter and voltmeter were used to measure the electrical input to the test specimen.

The air speed was measured by means of a Pitot tube in conjunction with a water manometer. The Pitot tube was located to one side of the test specimen and sufficiently far ahead that the presence of the specimen had no measurable effect on the precision of the reading.

TESTS

Tests were conducted with fin-plane/air-stream angles of 0° , 15° , 30° , 45° , 60° , 75° , and 90° at several heat inputs ranging from a minimum of 13 to a maximum of 248 B.t.u. per square inch of inner surface per hour at a constant air speed of 76 miles per hour. Tests were also conducted at the same angles, at a constant heat input of 107 B.t.u. per square inch per hour and at several air speeds from 30 to 150 miles per hour. Additional tests were made to obtain the air-flow patterns between the fins and around the cylinder for the 0° and 45° fin-plane/air-stream angles at an air speed of 76 miles per hour.

No readings were taken until all the cylinder temperatures had reached a constant value and the temperature of a point on the circumference of the test specimen near the

guard ring was within 2° F. of that of the corresponding point on the guard ring, which required approximately one hour. The average cylinder temperatures referred to in this report were obtained by plotting the circumferential temperatures in the form of a polar graph and by determining the radius of the circle having an equivalent area. All cylinder temperatures have been corrected to a cooling air temperature of 80° F.

PRECISION

Although the temperature of the outer wall of the test specimen was approximately the same as the temperature of the outer wall of the guard rings at adjacent points, the difference in temperature inside the test unit was appreciable. Computations made on the basis of measured temperature differences indicate that with a heat input of 107 B.t.u. per square inch per hour and an air speed of 76 miles per hour, the heat loss to the guard rings is approximately 6 per cent. This error should not affect the comparative value of these tests since the loss would probably be about the same for each fin-plane/air-stream angle. No attempt was made to correct for this error because the correction would be only an approximation. In tests on other finned specimens, the results of which will be published later, the error has been greatly reduced by the use of separately controlled heating elements in the end of each guard ring next to the test specimen.

The thermocouple wires were of very small diameter and consequently carried away a negligible quantity of heat. A test with a thermocouple mounted on the cylinder barrel showed that bringing the thermocouple wires straight out from the hot junction or keeping them in contact with the cylinder surface for about three inches but insulated electrically from the cylinder gave the same reading. Any change in the length of the thermocouple leads had little if any effect on the measurements, because the pyrometers had resistances of 224 to 232 ohms. The precision of the temperature measurements is within $\pm 5^{\circ}$ F.

The ammeter and voltmeter used in measuring the electrical input each had a precision of 0.5 per cent of full-scale deflection. The maximum error at the minimum input of 70 B.t.u. per square inch per hour is approximately 3 per cent.

The air-speed measurements are believed to be precise within ± 1 per cent. A velocity survey of the tunnel throat showed a uniform air speed over the entire area except at positions close to the walls.

RESULTS AND DISCUSSION

The circumferential temperature distribution obtained at 0° fin-plane/air-stream angle for the test specimen that was used in these tests is compared in Figure 5 with the temperature distribution obtained on the lower part of the barrel of a cylinder of the same design under engine operating conditions and without cowling. The similarity of the curves indicates that the heat flow through the cylinder and air-flow conditions are commensurate.

The three groups of curves in Figure 6 show the effect on cylinder temperatures of varying the angle of the air stream with respect to the fins at several different air speeds ranging from 30 to 150 miles per hour and at a constant heat input of 107 B.t.u. per square inch per hour. The curves show that considerably better cooling is obtained when the air is directed at an angle of approximately 45° with respect to the fins than is obtained when the air stream is perpendicular or parallel to the fins. At the low air speeds the range of the angle that gives the best cooling is from 40° to 55° and at the high velocities it is from 30° to 80° . The range of these angles is based on the rear-cylinder temperatures, because they are highest and are therefore given the most consideration.

When an air stream having a speed of 30 miles per hour is directed at the best angle with respect to the fins the reduction in temperature compared with parallel air flow is 115° , 127° , and 175° F. for the front, rear, and side, respectively; whereas, for an air speed of 150 miles per hour the reduction is 73° , 50° , and 67° for the same points, respectively. More complete data on these temperature reductions are given in Table I. As the heat input for the two conditions is the same the test-specimen temperatures for the low velocities will be the highest; consequently, the reduction in temperature caused by directing the air at the best angle is greater at the low air speeds. On a percentage basis, however, the reduction in the temperature difference between the specimen and cooling air at 30 miles per hour amounts to 42, 31, and 42 per cent for

front, rear, and side, respectively, and at 150 miles per hour the reduction amounts to 51, 29, and 43 per cent for the same points, respectively. Note that in front the reduction increases with air speed, whereas for the rear and side the percentage reduction is roughly the same for all speeds.

Figure 6 shows that the temperatures in the 90° position are practically the same as in the 0° position. That these temperatures are practically the same indicates that there must be considerable turbulence between the fins when the air is directed perpendicular to the fins. With the specimen in the 90° position the temperature in the front, rear, and side should be the same if the air flow is perpendicular to the fins. In these tests there was a difference in temperature at these points indicating that the air stream was not exactly perpendicular to the fins.

The cooling is improved with oblique air flow because the scouring action is greater than with parallel air flow. Air is an excellent heat insulator, consequently it is necessary that the boundary layer be reduced to the minimum thickness to obtain the best cooling. The cooling may also be improved because the cylinder forms an elliptical section at angles between 0° and 90° with respect to the air stream, resulting in more of the cooling area coming in contact with the air stream.

More complete data on the heat distribution with parallel, perpendicular, and oblique (45°) air flow at air speeds of 76 and 150 miles per hour are shown in Figure 7. Note that the temperatures with parallel air flow are higher at some points than the temperatures with perpendicular air flow. These curves show more clearly than the curves in Figure 6 the lack of uniformity of temperatures for the 90° position owing to the fact that the air stream is not exactly perpendicular to the fins.

The maximum and minimum temperatures at various heat inputs, at 0° , 45° , and 90° angles, and at a constant air speed of 76 miles per hour are shown in Figure 8. Within the range of these tests the test-specimen temperatures varied directly with the heat input.

Figure 9 shows the variation of the heat-transfer coefficient U_p at various air speeds and at several dif-

ferent fin-plane/air-stream angles. This coefficient is the number of B.t.u. dissipated per square inch of inside wall area per hour per degree temperature difference. Note that the greatest quantity of heat is carried away for angles of from 30° to 45° and the least heat for an angle of 90° at the low air speeds.

Patterns of the air flow around the cylinder at an air speed of 76 miles per hour are shown in Figure 10. These patterns were obtained by clamping a guard ring to the test section having the adjacent end fins painted with lampblack and kerosene and testing the assembly at the 0° and 45° positions. A photograph of the flow in the vicinity of the cylinder is included. This pattern was produced on a flat, polished, aluminum plate inserted between the guard ring and the test section.

The position on the cylinder where the flow breaks away is clearly defined in these pictures. This position is about 100° from the front of the cylinder for the 0° fin-plane/air-stream angle. This breakaway also occurs on the windward side of the fins for the 45° angle at about 115° from the front of the cylinder. The existence of dead-air regions at the front and at the breakaway positions is proved by the increase in temperature at these points as shown in Figure 7.

When applying these test results to aircraft engine cylinders under flight conditions it should be remembered that the results presented were obtained under the conditions of air flow in the wind tunnel. Because of the turbulence set up by the revolving propeller in flight the quantity of heat dissipated by varying the fin-plane/air-stream angle may be different than the wind-tunnel tests indicate. The cowling over the forward part of the crankcase of a great many engines does effect a nonparallel flow over the fins of the cylinders. Any improvement to be gained would depend entirely upon the previous direction of flow. In a recent cowling investigation in which a cowling was designed to give obliquely directed air over the cylinders, the cylinder temperatures were appreciably reduced by the use of this cowling.

CONCLUSIONS

The results of these tests show:

1. That the best angle to direct the cooling air with respect to the cylinder fins is about 45° and is independent of the air speed.
2. That the temperature difference between the finned cylinder and the air stream for a given heat input is reduced 30 to 50 per cent with a fin-plane/air-stream angle of 45° as compared with parallel air flow. The amount of the reduction depends on the velocity and the position on the cylinder. With the same average cylinder temperature the total heat input to the cylinder can be increased 50 per cent with a fin-plane/air-stream angle of 45° as compared with air flow parallel with the fins.
3. That the quantity of heat dissipated is proportional to the temperature difference.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 29, 1932.

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2. Gibson, A. H.: The Air Cooling of Petrol Engines. Proceedings of the Institute of Automobile Engineers, 1920, XIV, pp. 243-275.
3. Schey, Oscar W., and Biermann, Arnold E.: The Effect of Cowling on Cylinder Temperatures and Performance of a Wright J-5 Engine. T.R. No. 332, N.A.C.A., 1929.
4. Schey, Oscar W., Johnson, Ernest, and Gough, Melvin N.: Comparative Performance Obtained with KF7C-1 Airplane Using Several Different Engine Cowlings. T.N. No. 334, N.A.C.A., 1930.

TABLE I

CYLINDER TEMPERATURE DATA

Air-stream velocity	Finned specimen temper- atures with parallel air flow	Temper- ature with best fin- plane/air- stream angle	Specimen tempera- ture with parallel air flow less room tempera- ture of 80° F.	Differ- ence be- tween speci- men tempera- ture with parallel air flow and with best fin-plane/ air-stream angle	Percentage reduction based on maximum possible reduction
m.p.h.	°F	°F	°F	°F	
Rear					
30	490	363	410	127	31.0
60	355	260	275	95	34.5
90	295	225	215	70	32.5
120	263	207	183	56	30.6
150	250	200	170	50	29.4
Front					
30	357	240	277	117	42.2
60	275	187	195	88	45.1
90	243	168	163	75	46
120	232	158	152	74	48.7
150	223	150	143	73	51
Side					
30	495	320	415	175	42.2
60	315	235	235	80	34
90	265	205	185	60	32.4
120	245	186	165	59	35.8
150	237	170	157	67	42.7

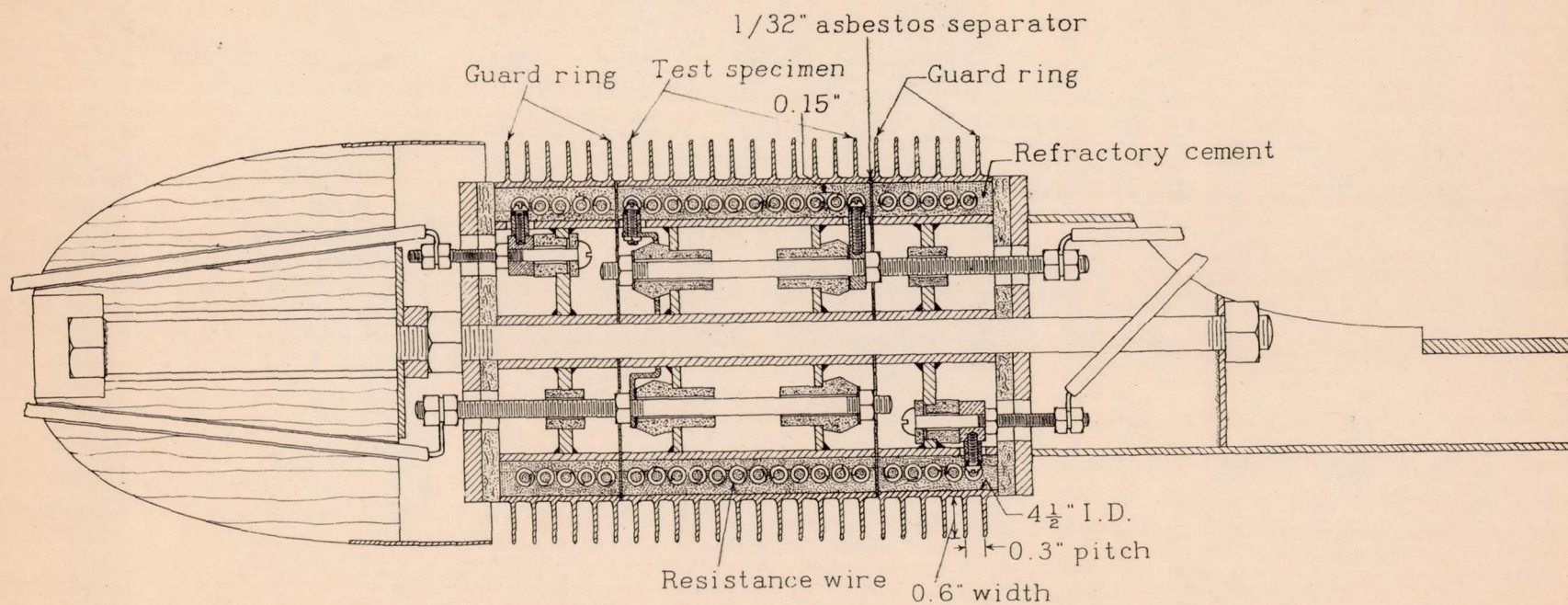


Fig. 1 Details of construction of test unit.

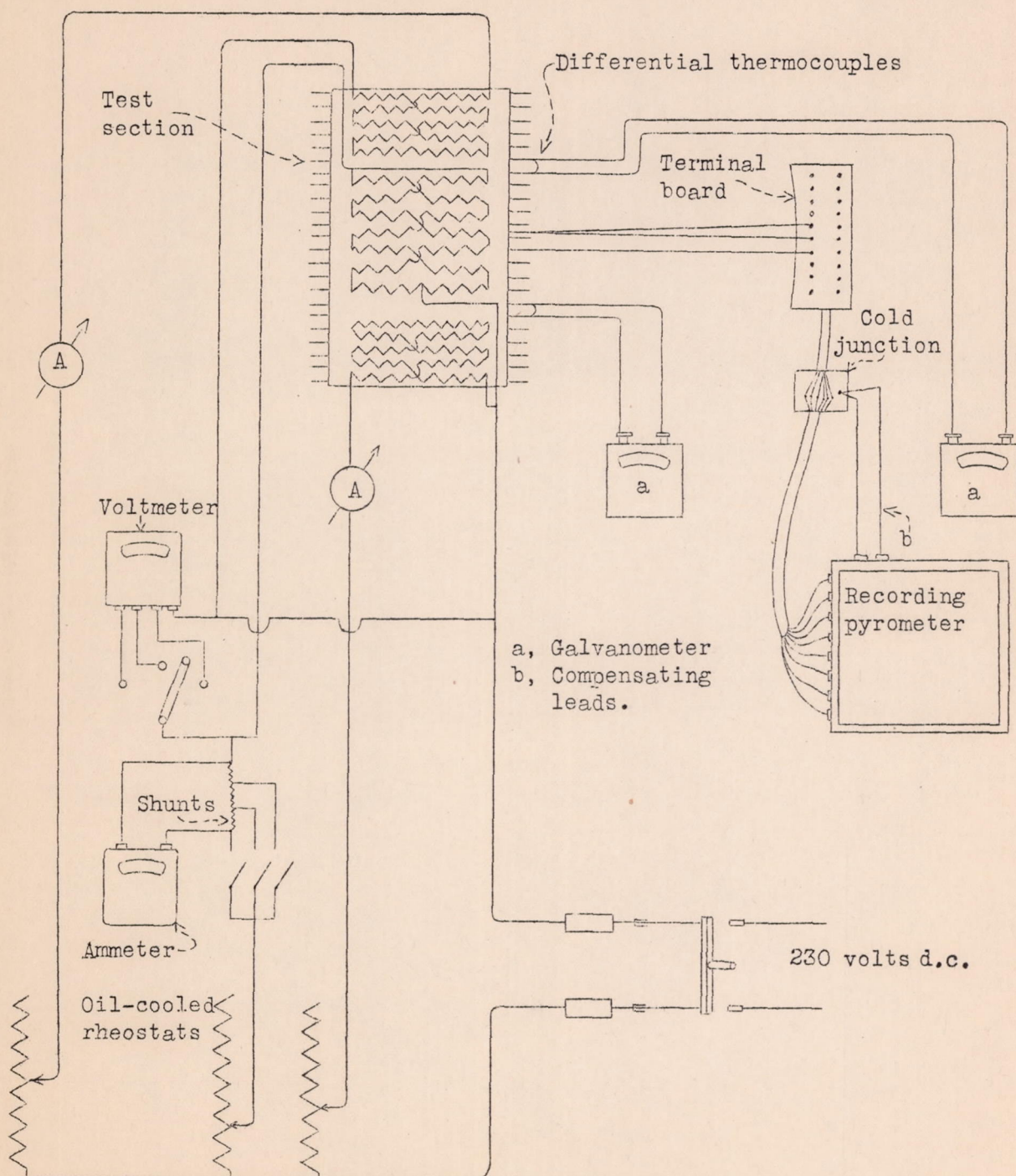


Fig.2 Wiring diagram of test unit, rheostats, and instruments.

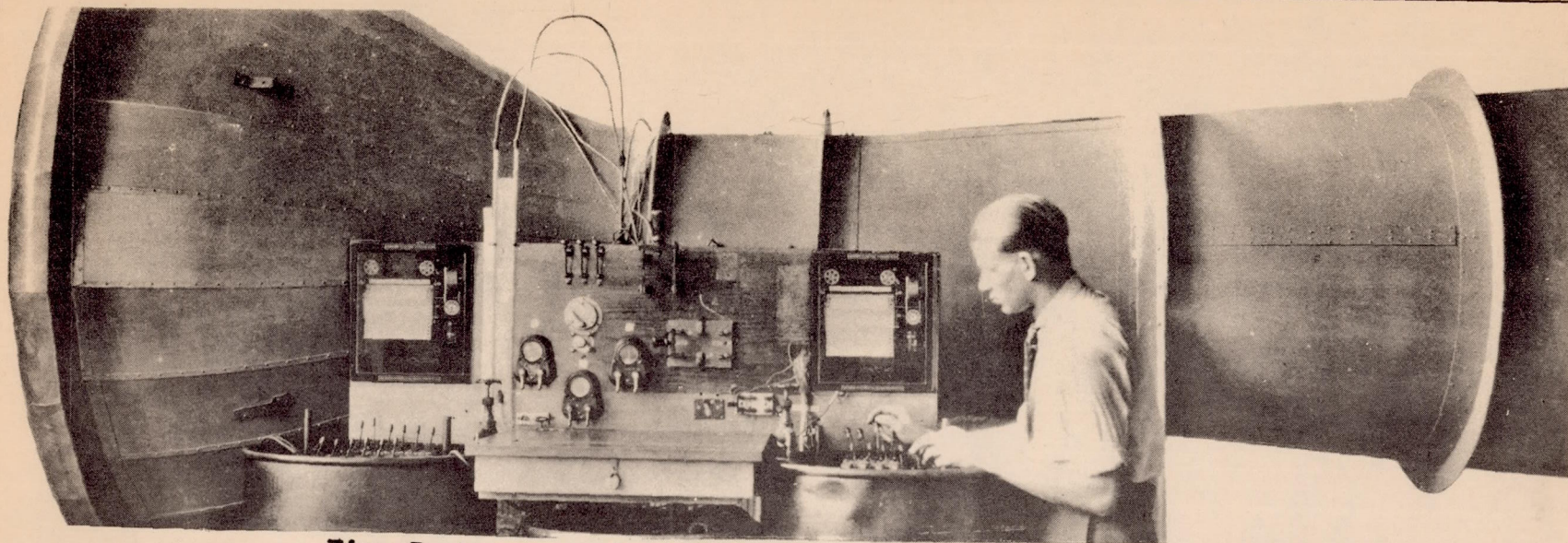


Fig. 3 Arrangement of the wind tunnel, rheostats, and instruments.

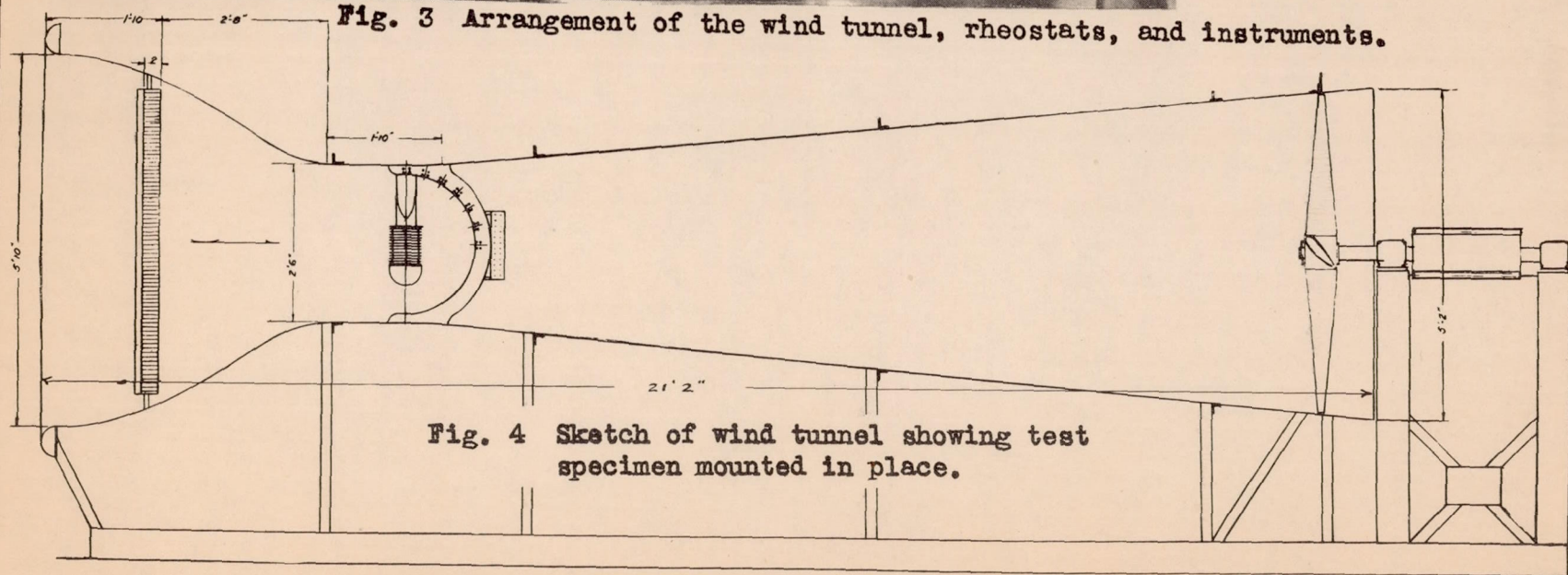


Fig. 4 Sketch of wind tunnel showing test specimen mounted in place.

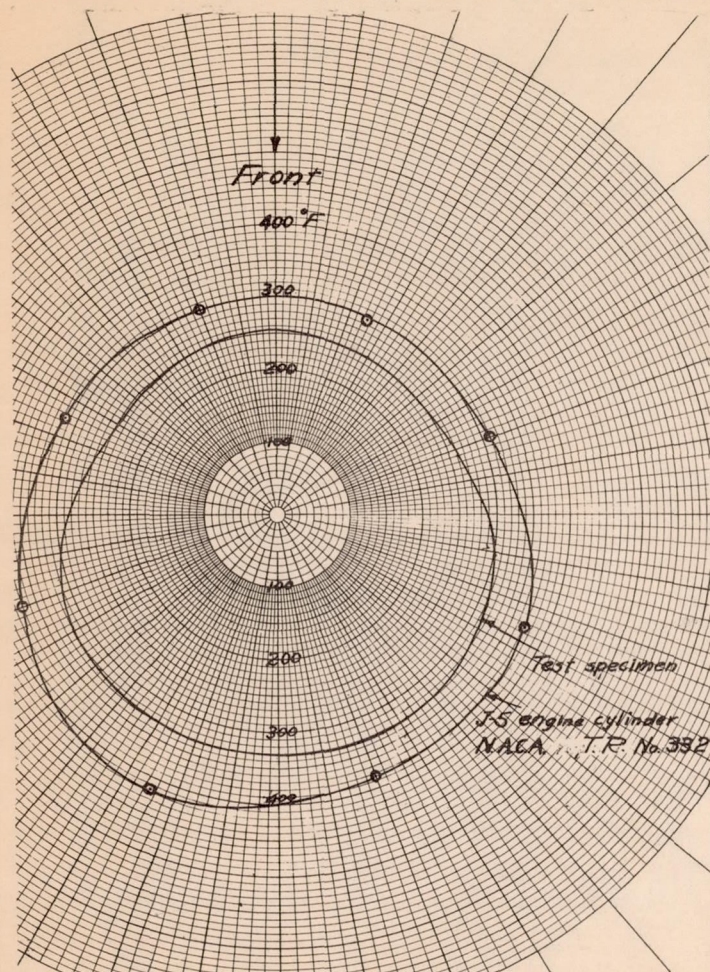


Fig. 5 Comparison of the circumferential temperatures of the test specimen at 76 m.p.h. and at a heat input of 107 B.t.u. per sq. in. per hour with those of the lower part of the barrel of a J-5 engine cylinder at 80 m.p.h. and at full-throttle condition.

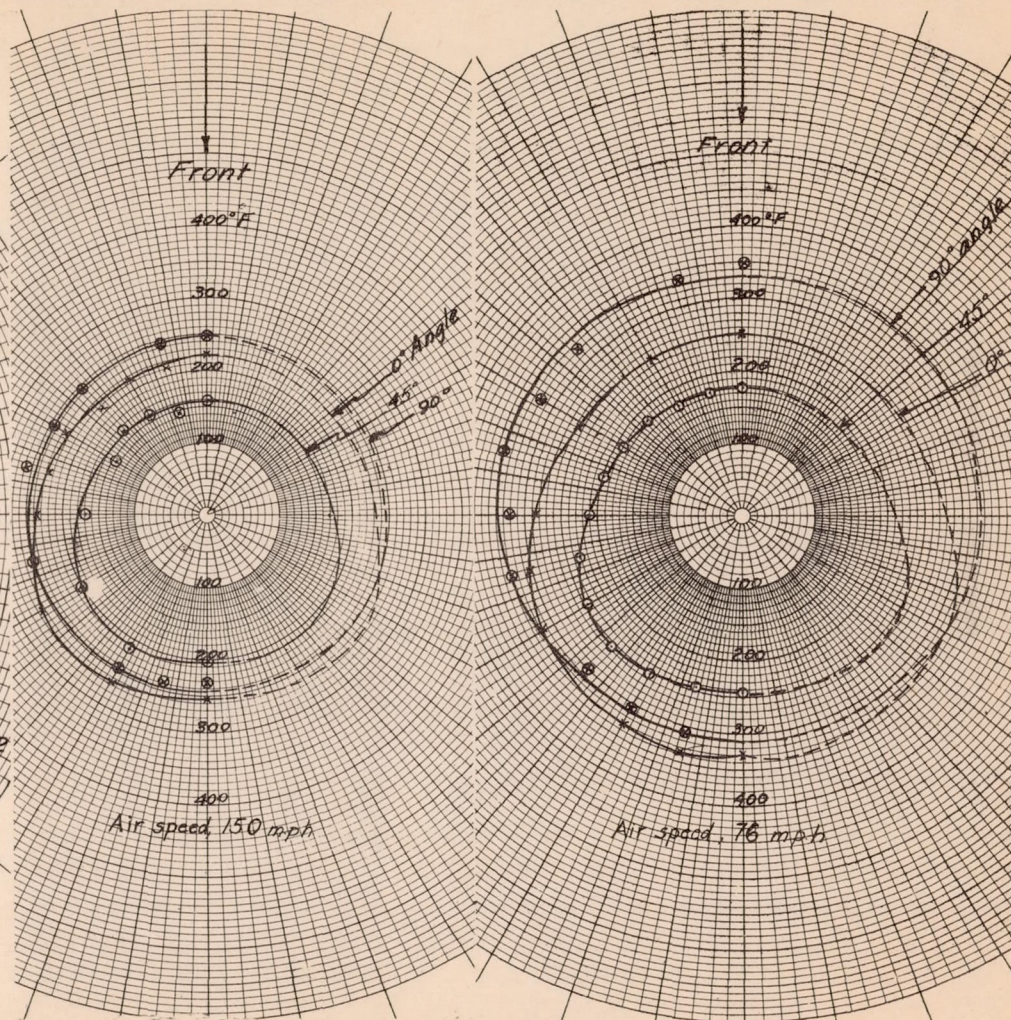


Fig. 7 Circumferential temperature distribution at 76 and 150 m.p.h. with a heat input of 107 B.t.u. per sq. in. per hour at fin-plane/air stream angles of 0°, 45°, and 90°.

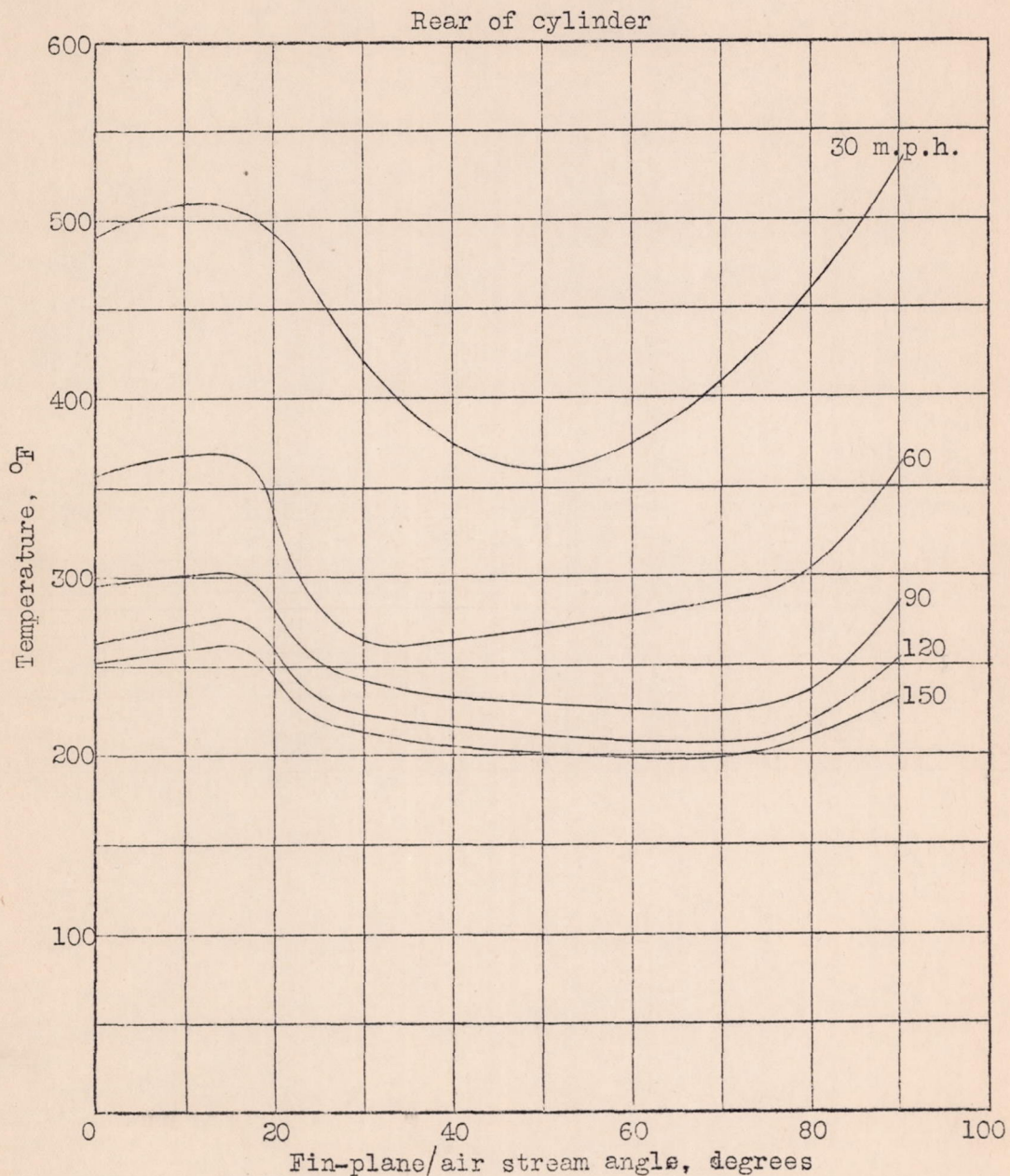


Fig.6 The effect of fin-plane/air stream angle upon the temperature of the rear of the cylinder at a constant heat input of 107 B.t.u. per sq. in. per hour and at various air speeds.
(Continued on next two pages)

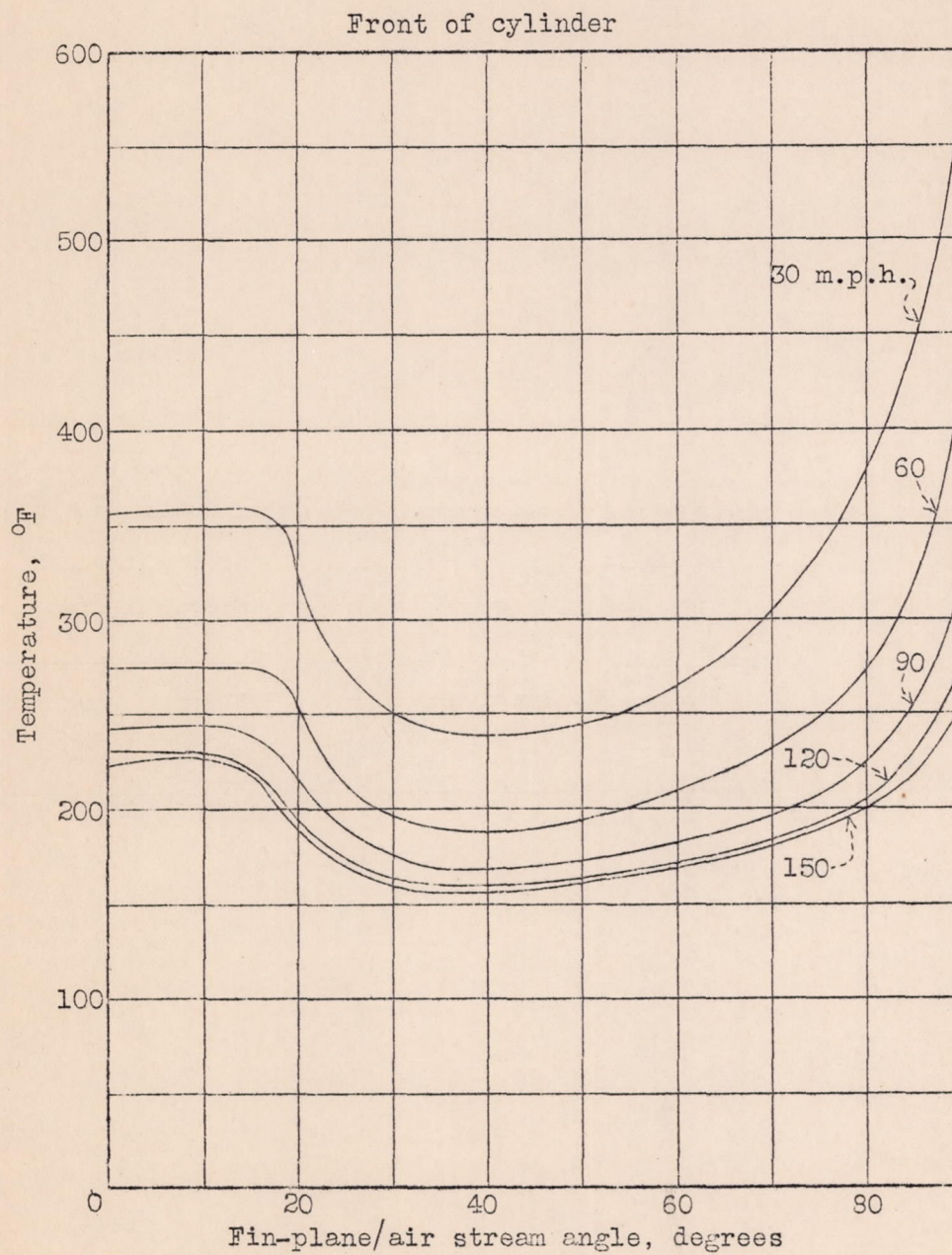


Fig.6 The effect of fin-plane/air stream angle upon the temperature of the front of the cylinder at a constant heat input of 107 B.t.u. per sq. in. per hour and at various air speeds.
(Continuation of Fig.6)

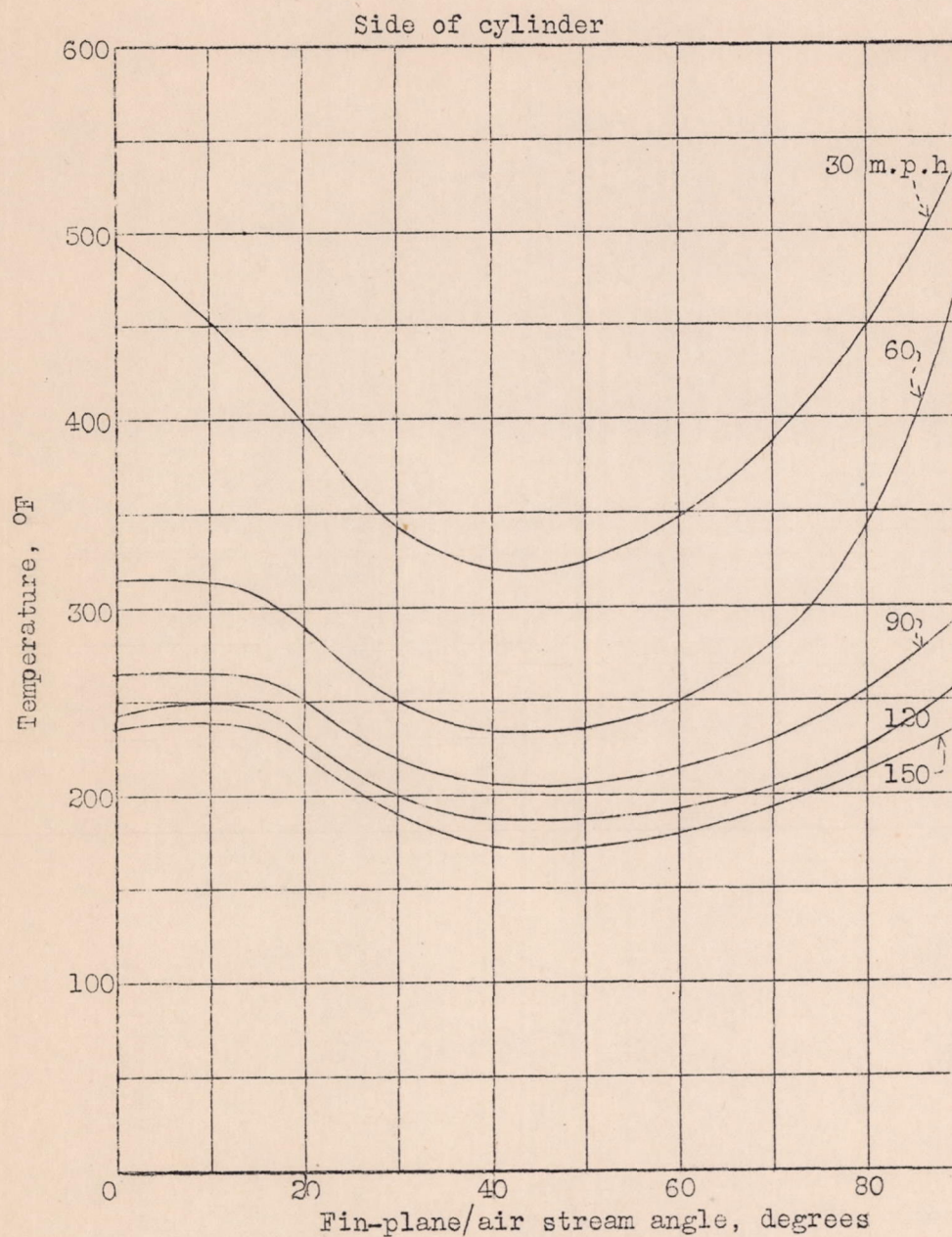


Fig.6 The effect of fin-plane/air stream angle upon the temperature of the side of the cylinder at a constant heat input of 107 B.t.u. per sq. in per hour and at various air speeds.

(Conclusion of Fig.6)

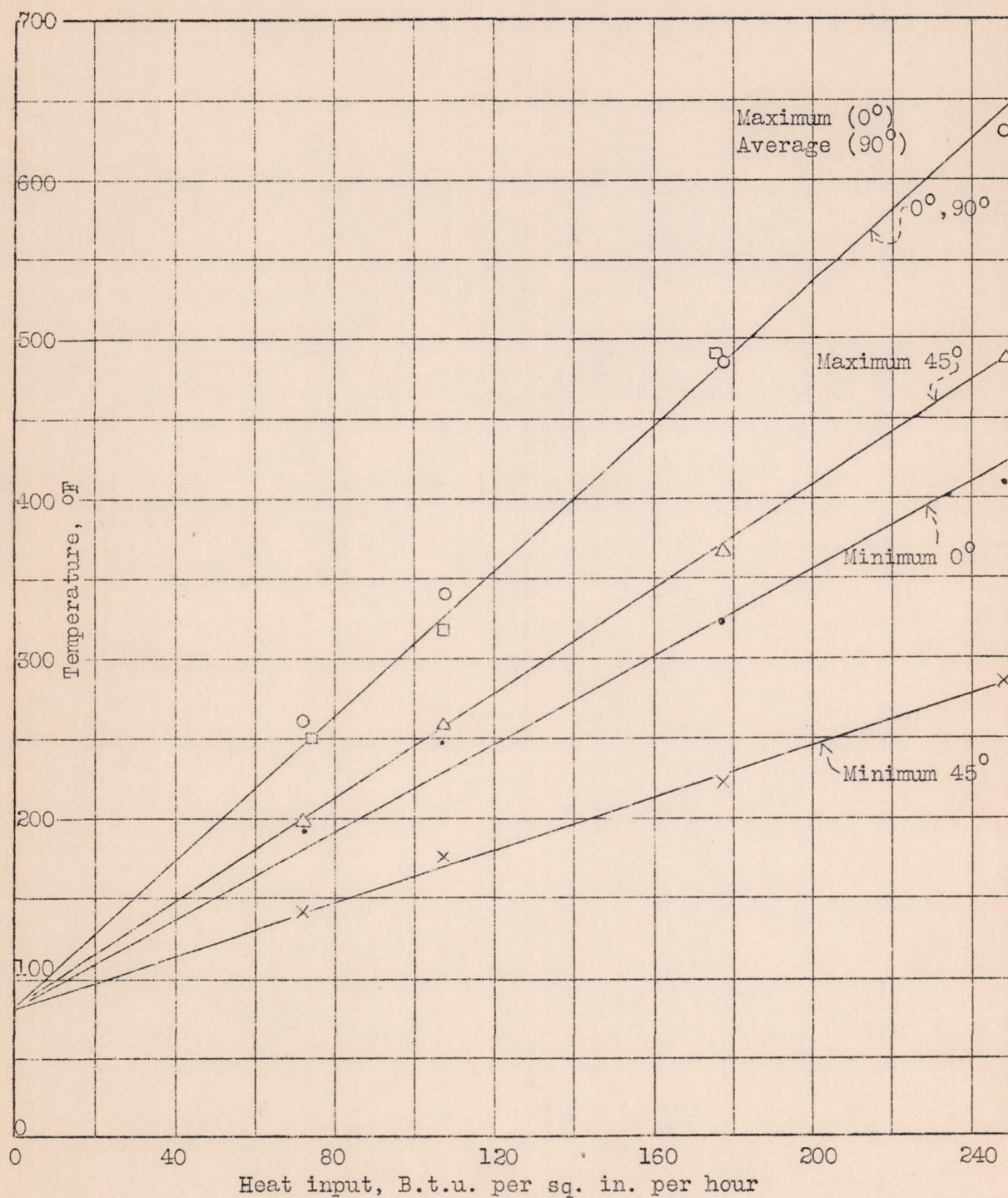


Fig.8 The variation of maximum and minimum cylinder temperatures with different heat inputs at 0°, 45°, and 90° angles and at a constant air speed of 76 m.p.h.

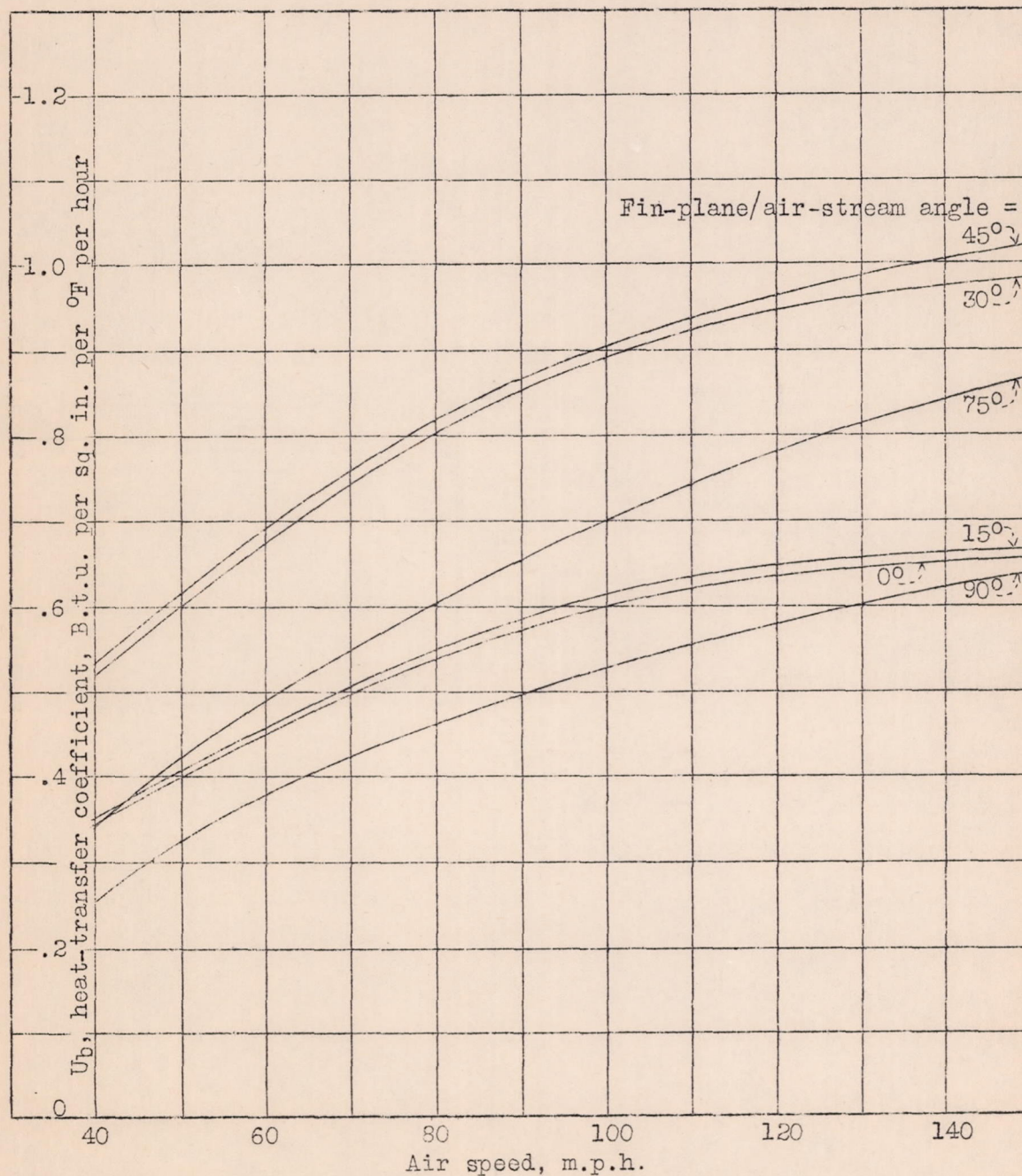
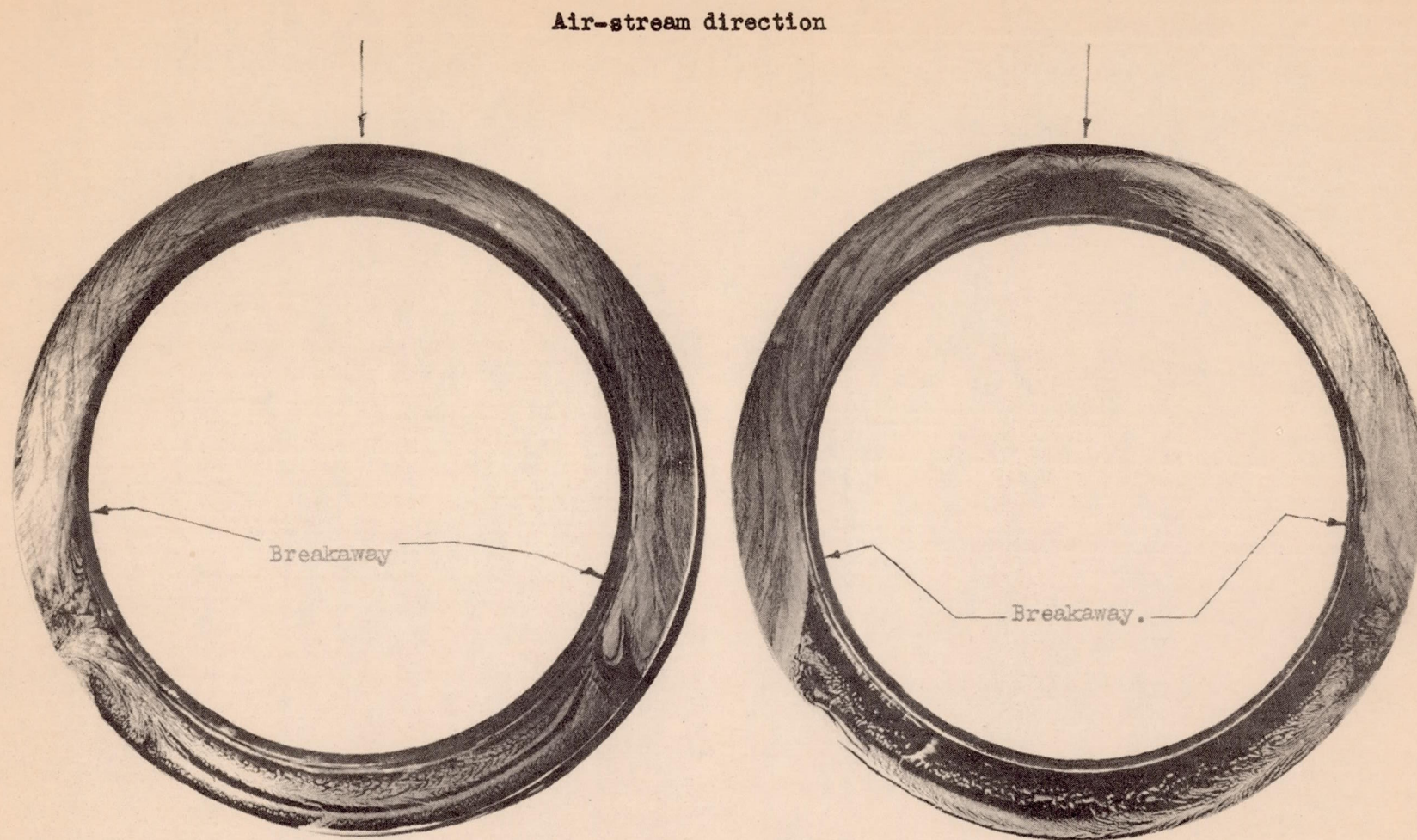


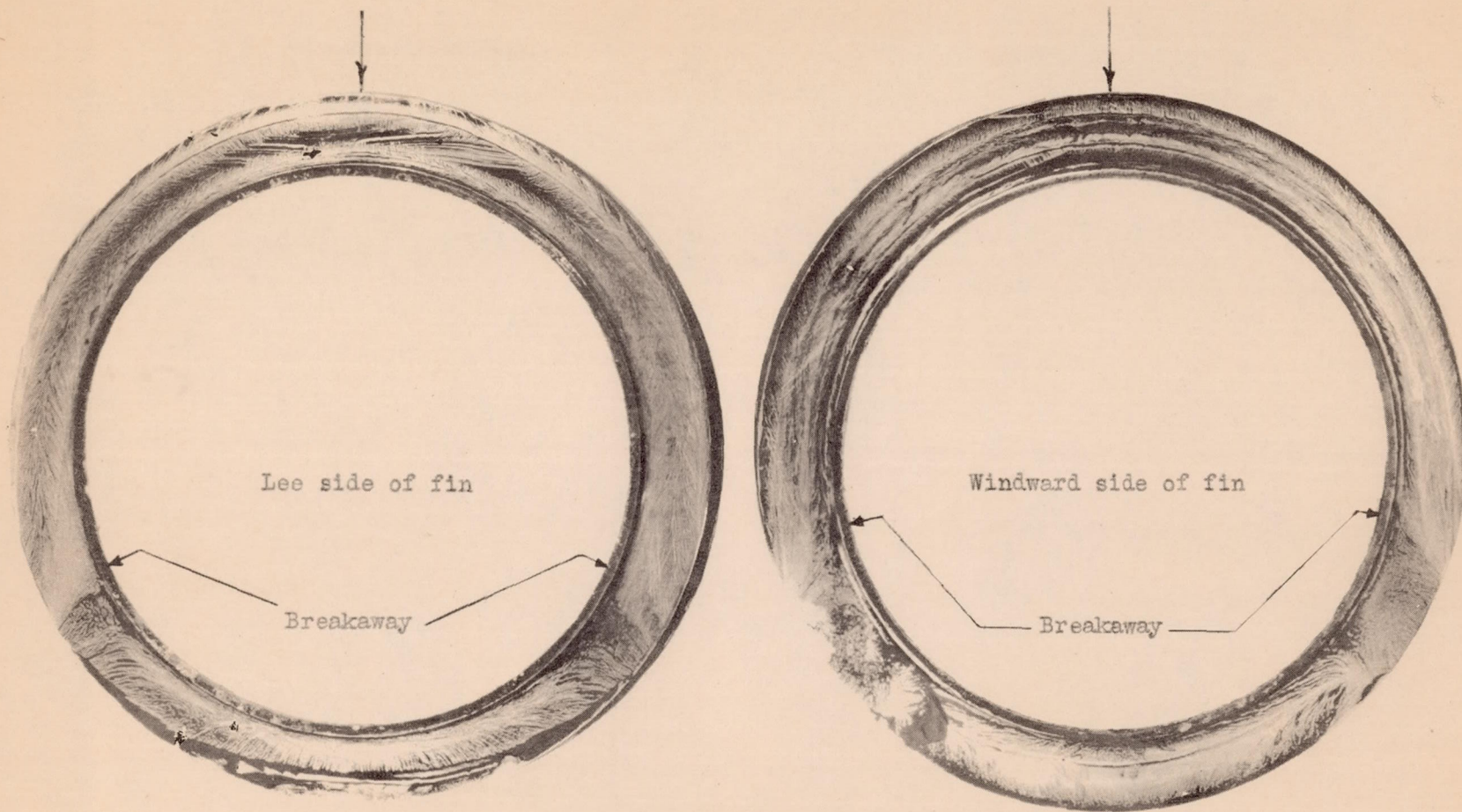
Fig.9 The effect of air speed on the heat transfer coefficient U_b at a heat input of 107 B.t.u. for several fin-plane/air-stream angles.



Adjacent fin surfaces at 0° fin-plane / air-stream angle.

Fig. 10 Air-flow patterns at 76 m.p.h.
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Air-stream direction

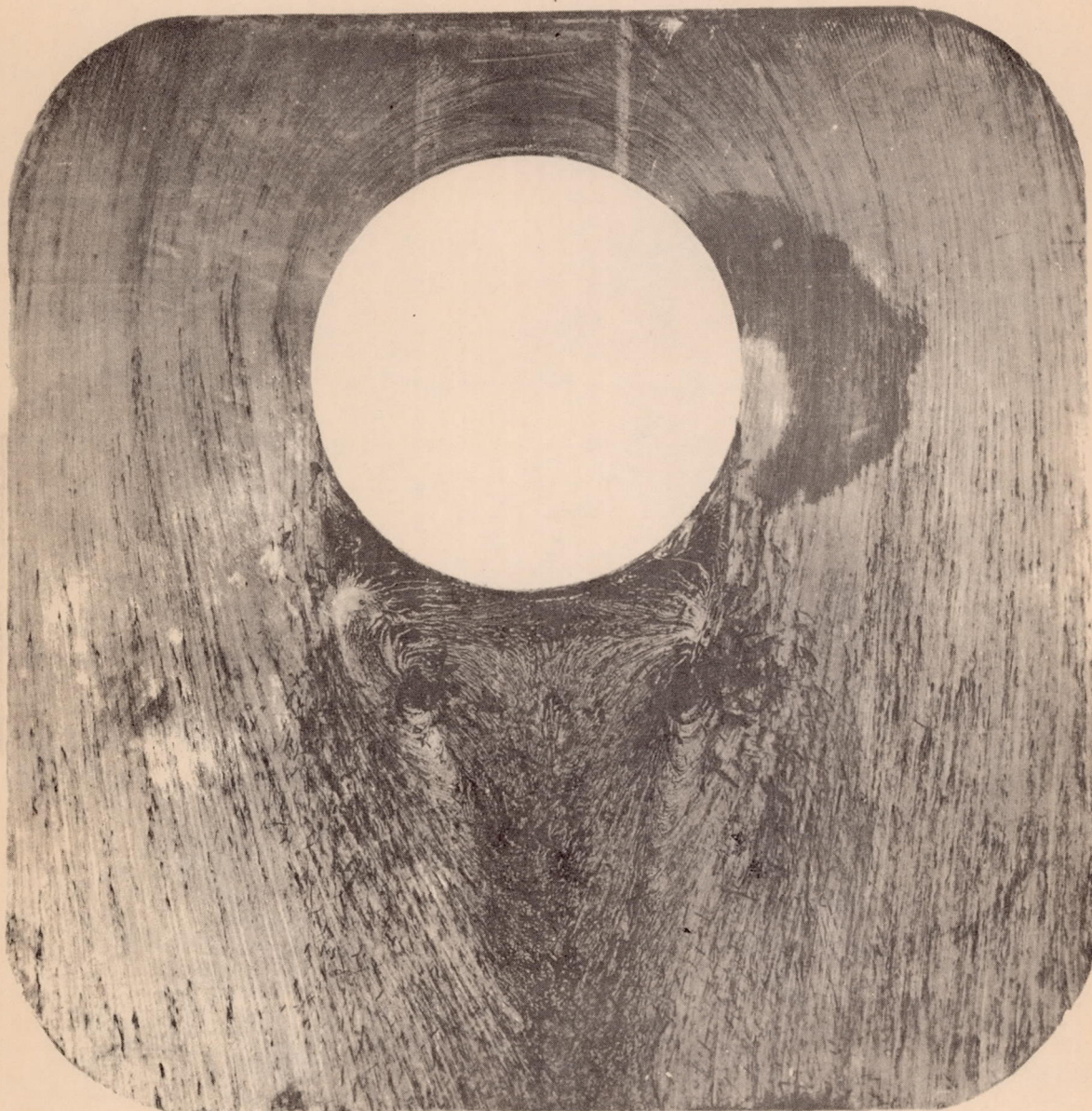


Adjacent fin surfaces at 45° fin-plane / air-stream angle.

Fig. 10 Air-flow patterns at 76 m.p.h.
(Continuation of Fig. 10)

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Air-stream direction



Flow around cylinder at 0° angle

Fig. 10 Air-flow patterns at 76 m.p.h.
(Continuation of Fig. 10)